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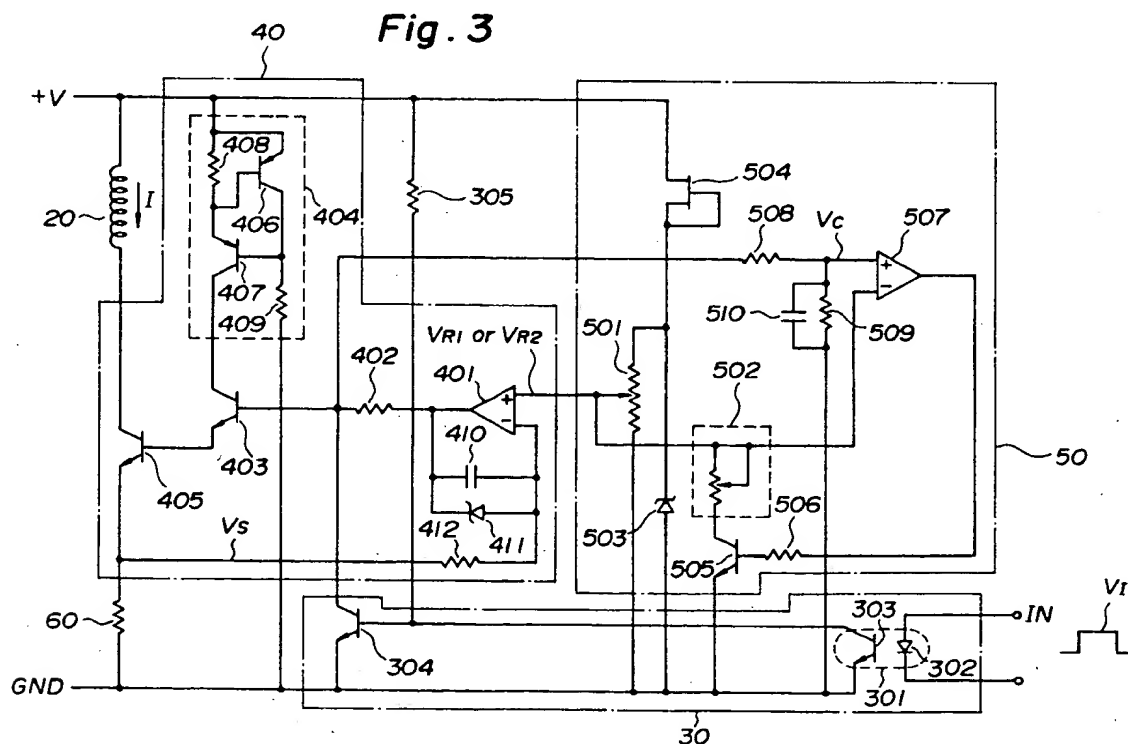
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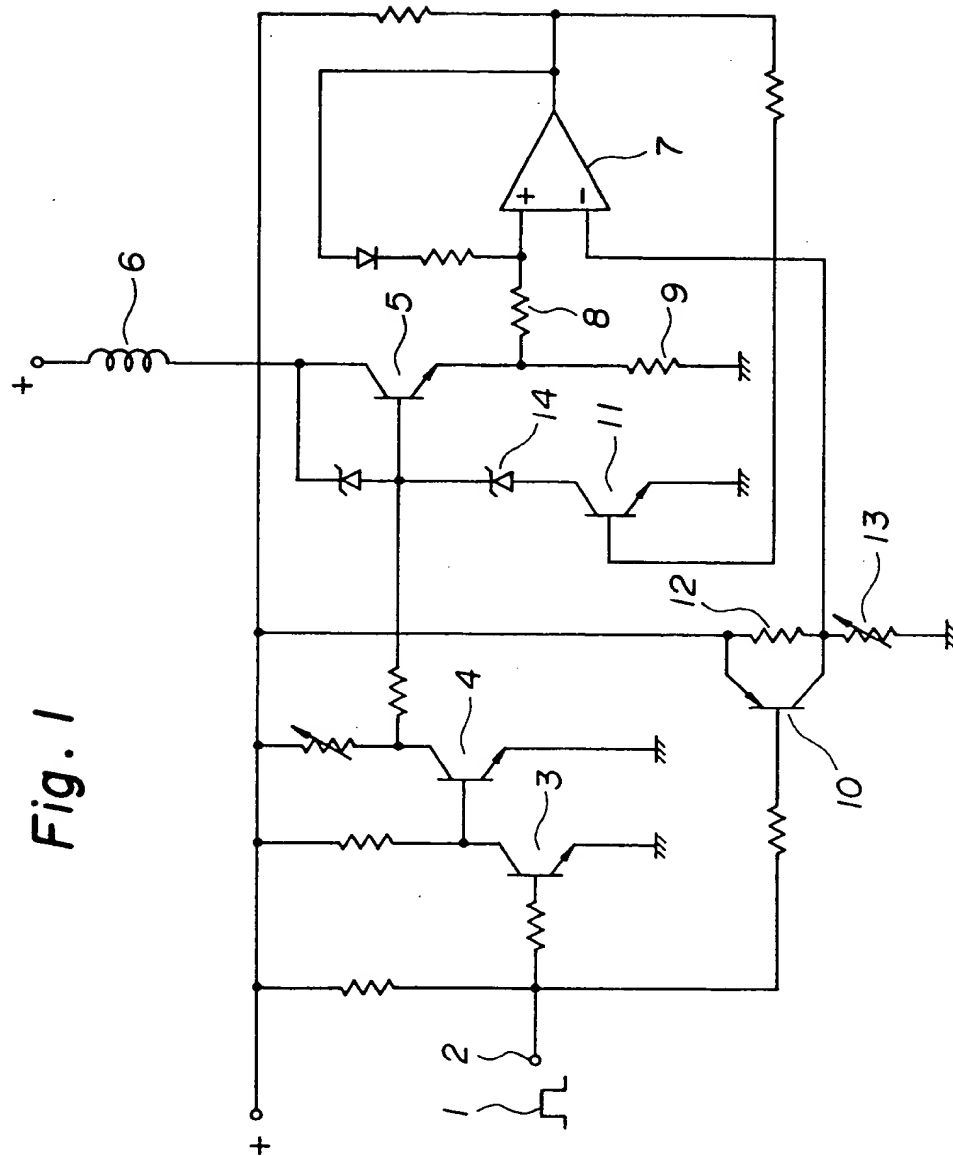
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## (54) Current controlling device for electromagnetic windings

(57) A current-controlling device comprises an opto coupled input circuit (30), means (50) for supplying a first stable reference voltage ( $V_{R1}$ ) or a second stable reference voltage ( $V_{R2}$ ) lower than the first, a detecting resistor (60) for detecting current flowing through an electromagnetic winding, and means (40) for supplying the electromagnetic winding with a starting current and a holding current. The starting current after initially increasing is regulated to a constant value by the first reference voltage. The second reference voltage is supplied instead of the first reference voltage after a predetermined time and until the end of the driving signal to regulate the holding current to another lower constant value.



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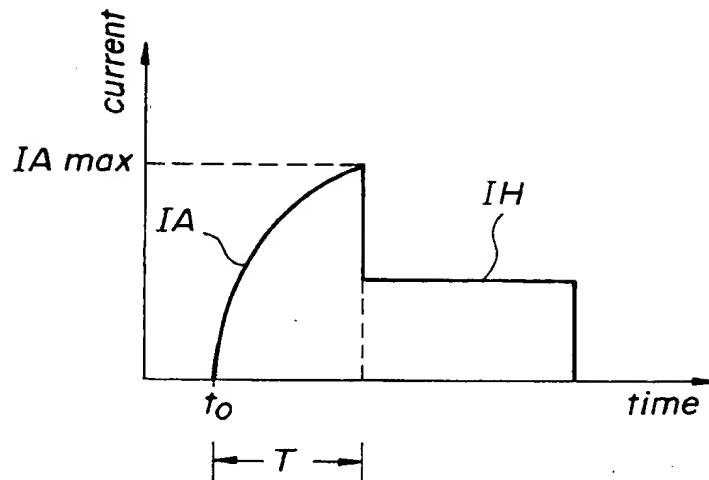
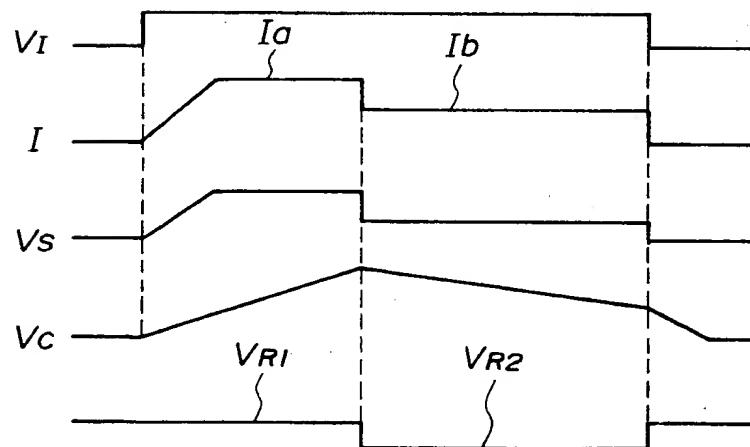
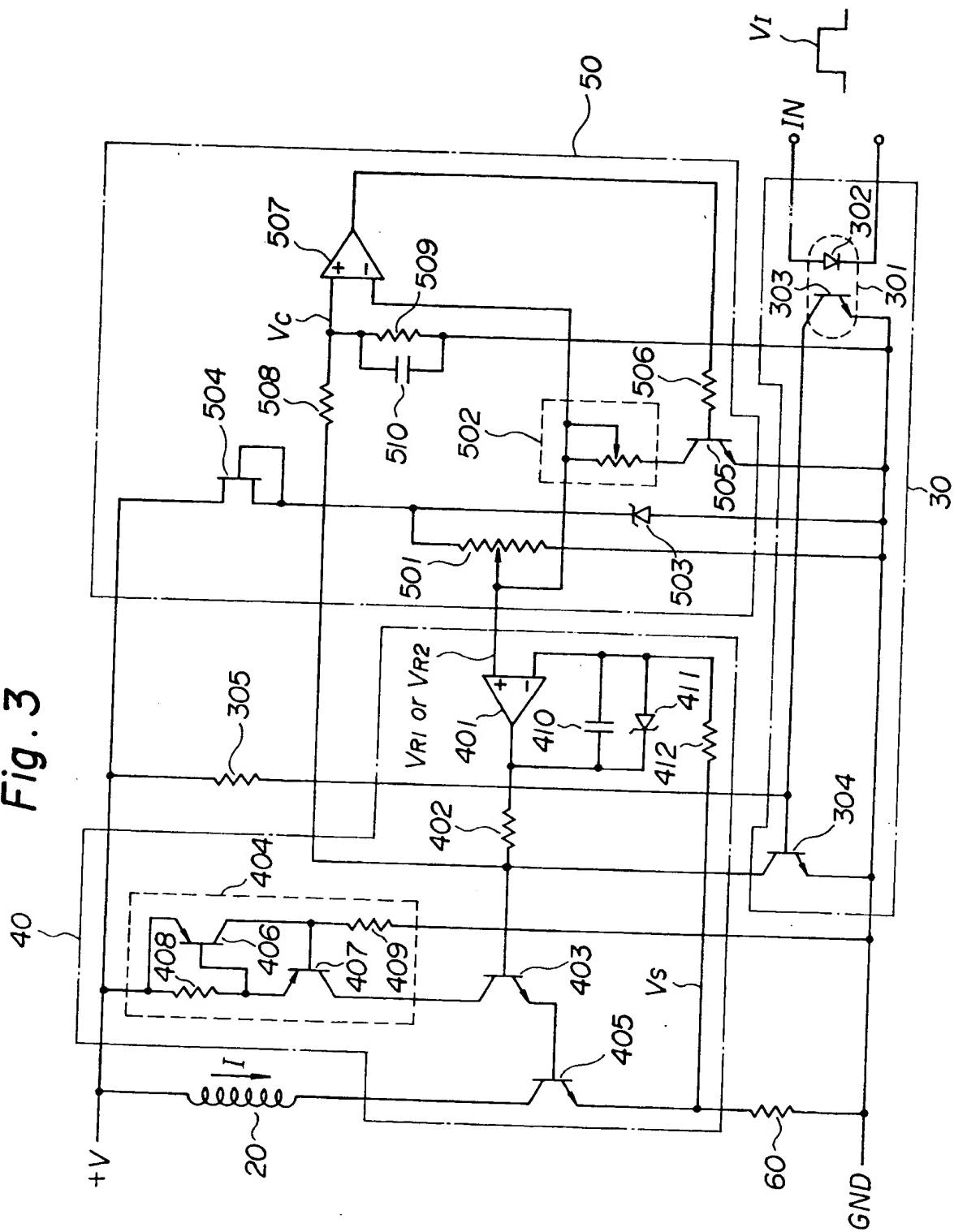
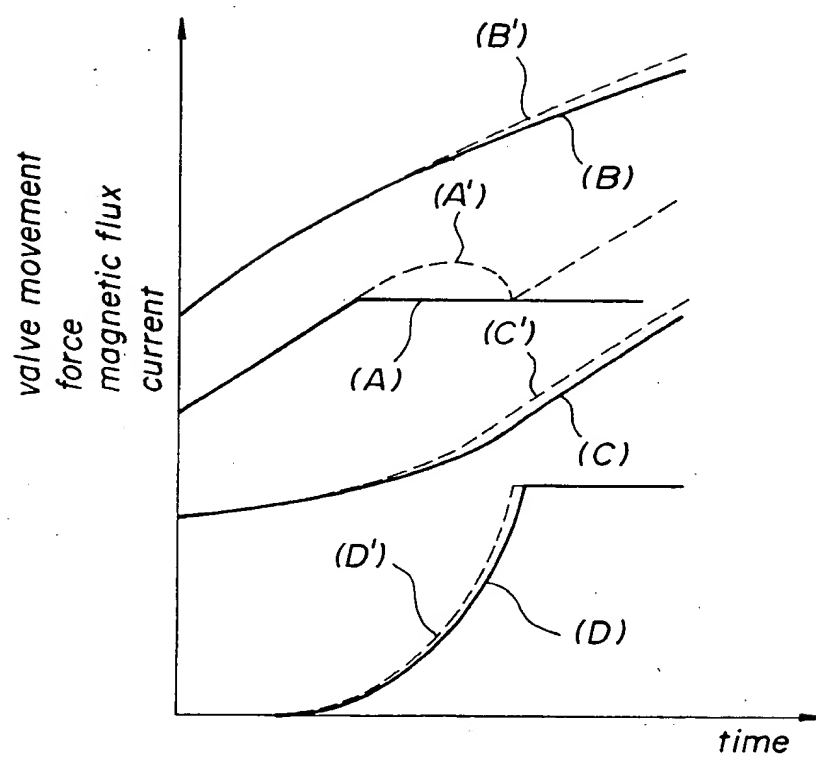
**Fig. 2****Fig. 4**

Fig. 3



*Fig. 5*

## SPECIFICATION

**Current controlling device for electromagnetic windings**

The present invention relates to a current-controlling device for an electromagnetic winding, and in particular, relates to a current-controlling device for controlling a starting current and a holding current supplied to an electromagnetic winding of a solenoid valve, for example.

When an electromagnetic appliance such as a solenoid valve, an electromagnetic nozzle or an electromagnetic relay is driven, in general, a large starting current is supplied to an electromagnetic winding thereof at the time of a starting operation, after which the current is reduced to a holding current lower than the starting current in order to hold the condition.

Figure 1 shows a prior controlling device to perform the above current control, and Fig. 2 shows a characteristic curve of current flowing through an electromagnetic winding of the current flowing through an electromagnetic winding of the circuit in Fig. 1. This current-controlling device has been shown in U.S. Patent No. 4,245,296.

In those figures, when a driving signal 1 is not supplied, an input terminal 2 is at zero potential. Consequently, transistors 3 and 5 are in "off" state, and a transistor 4 is in "on" state. Therefore, current does not flow through an electromagnetic winding 6. A comparator 7 at its positive input terminal is grounded through resistors 8 and 9, and its negative input terminal is supplied with a source voltage by mean of a transistor 10 in the "on" state. Therefore, the output level of the comparator 7 is at a low level L, and a transistor 11 is not conductive. If the driving signal 1 appears at the input terminal 2 at time point  $t_0$  of Fig. 2, the potential of the input terminal 2 becomes high, thereby the transistors 3, 5 are conductive, and the transistors 4, 10 are cut off. When the transistor 10 is cut off, the negative input terminal of the comparator 7 is supplied with the source voltage divided by resistors 12 and 13. When the transistor 5 is rendered conductive, a starting  $I_A$  flows through the electromagnetic winding 6 and rises gradually, and consequently the voltage drop across the resistor 9 increases. If the starting current  $I_A$  reaches the maximum value  $I_{A_{max}}$ , the voltage applied to the positive input terminal of the comparator 7 exceeds the voltage applied to its negative input terminal, and the output level of the comparator 7 changes to a high level H, causing a transistor 11 to conduct. The transistor 11 and a zener diode 14 in series with transistor 11 are connected in parallel with the base-emitter circuit of the transistor 5 and the resistor 9. Consequently, the presence of the zener voltage in the series connection, causes

the current which flows through the electromagnetic winding 6 to decrease from  $I_{A_{max}}$  to a lower holding current  $I_H$ . If the driving signal 1 comes to an end, the potential at the input terminal 2 becomes zero, and the circuit is returned to the initial condition.

However, the prior controlling circuit has disadvantages as described below.

With this prior circuit, because the starting current  $I_A$  is allowed to rise freely to a maximum value  $I_{A_{max}}$ , the increasing heat loss in the electromagnetic winding may rise to an undesirable value. To reduce the heat loss, it would be preferable for the maximum value  $I_{A_{max}}$  of the starting current to be given a lower value. In the prior art, however, a reduction of the maximum value  $I_{A_{max}}$  is accompanied by a narrowing of the starting period T, and this could result in preventing the driving of, for example, a solenoid valve to be controlled. Consequently, in the prior art, since the reduction of the maximum value  $I_{A_{max}}$  presents difficulties, the large heat loss due to the large starting current is accepted.

Also, in the prior art, since the large current flows until the starting current attains the maximum value  $I_{A_{max}}$  even if the solenoid valve has been completely opened before the end of the starting period T, the heat loss may increase still more.

Further, in the prior art, since the reference voltage of the comparator 7 is obtained by dividing the source voltage by the resistors 12 and 13, the reference voltage is easily varied with the fluctuation of the source voltage. Therefore, the characteristics of the current flowing through the electromagnetic winding vary, and stable control of the solenoid valve may be prevented.

It is an object, therefore, of the present invention to overcome the disadvantages and limitations of the above-mentioned prior current controlling device by providing a current controlling device which can reduce heat loss in the electromagnetic winding.

A current-controlling device according to the invention comprises an input circuit for receiving a driving signal; reference voltage supply means responsive to the driving signal to supply a first reference voltage or a second reference voltage lower than the first reference voltage, the first and second reference voltages being controlled at substantially constant respective values, the first reference voltage being supplied up to a predetermined time after the input of the driving signal and the second reference voltage being supplied from the predetermined time after the input of the driving signal until the end of the driving signal; a detector resistor connected to provide a signal representing current flowing through the electromagnetic winding; and current-control means receiving the first and second reference signals and the current-representing signal for supplying the electromagnetic winding with a



starting current and a holding current, the starting current after initially increasing following the receipt of a driving signal being regulated to a substantially constant value under the control of the said current-representing signal and the first reference voltage, and the holding current being regulated to another substantially constant value lower than the first constant value under the control of the current-representing signal and the second reference voltage.

The present invention will be better understood by reference to the following description and accompanying drawings wherein;

*Figure 1*, to which reference has already been made, is a circuit diagram of a current-controlling device of the prior art;

*Figure 2* is a characteristic curve of current flowing through an electromagnetic winding of the circuit of *Fig. 1*;

*Figure 3* is a circuit diagram of a current-controlling device embodying the present invention;

*Figure 4* is an operational time chart for the circuit of *Fig. 3*; and

*Figure 5* shows starting characteristic curves given by the constant current control of the starting current characteristic shown in *Fig. 4* and the uncontrolled starting current characteristic shown in *Fig. 2*.

In the drawing, *Fig. 3* shows a current-controlling device embodying the invention for driving an electromagnetic winding 20 of a solenoid valve. It will be clear that when the electromagnetic winding 20 is applied to an electromagnetic nozzle or an electromagnetic relay, the device in *Fig. 3* can also be used.

The current-controlling device comprises an input circuit 30 for receiving a driving signal VI, current control means 40 for controlling the current flowing through the electromagnetic winding 20, reference voltage supply means 50 for supplying the current control means 40 with a first reference voltage  $V_{R1}$  and a second reference voltage  $V_{R2}$  lower than the first reference voltage  $V_{R1}$ , and a detecting resistor 60 for detecting the current which flows through the electromagnetic winding 20.

An input terminal IN of the input circuit 30 is connected to a photodiode 302 of a photo-coupler 301. A photo-transistor 303 of the photo-coupler 301 is grounded at its emitter, and its collector is connected to the base of a switching transistor 304. The base of the transistor 304 is also connected through a resistor 305 to the power source line. An emitter of the transistor 304 is grounded, and its collector is connected to the current control means 40. The transistor 304 is conductive when the driving signal VI is not supplied, because the photo-transistor 303 is then cut off. On the other hand, when the driving signal VI is supplied, the transistor 304 is cut off because the photo-transistor 303 is conductive.

The collector of the switching transistor 304 is connected through a resistor 402 to the output of a comparison amplifier 401 of the current control means 40. The junction point between the collector of the transistor 304 and the resistor 402 is connected to the base of a forward-stage driving transistor 403. The transistor 403, with a current-limiting circuit 404 to which its collector is connected and a final-stage driving transistor 405, constitutes a driving circuit of the electromagnetic winding 20. The emitter of the forward stage driving transistor 403 is connected to the base of the final-stage driving transistor 405. The current-limiting circuit 404 which comprises two transistors 406, 407 and two resistors 408, 409 limits the collector current of transistor 403. By means of this limiting, the extreme saturation of the final-stage driving transistor 405 is prevented. The collector of the transistor 405 is connected to one end of the electromagnetic winding 20, and its emitter is connected to one end of the detecting resistor 60. The other end of the electromagnetic winding 20 is connected to the power source line. The other end of the detecting resistor 60 is grounded. The current I flowing through the electromagnetic winding 20 is supplied by the final stage driving transistor 405.

The base current of the transistor 405 is the emitter current of the forward-stage driving transistor 403. The base current of the transistor 403 is supplied from the comparison amplifier 401.

The comparison amplifier 401, together with a resistor 402, a capacitor 410, a Zener diode 411 and a resistor 412, constitute a comparison amplifier circuit. Preferably, the comparison amplifier 401 is composed of an operational amplifier of which input stage transistors are of PNP type (for example,  $\mu$ PC1251C of Nippon Electric Co., Ltd.). For such an operational amplifier, the lowest value of the input voltage range is 0 (V) since no voltage remains at the input stage, while for an operational amplifier which has NPN transistors in its input stage, the lower value of the input voltage range is a higher value than 0 (V) because of residual voltage in the input stage. Therefore, if the comparison amplifier 401 is composed of the preferable operational amplifier, the resistance value of the detecting resistor 60 relative to the electromagnetic winding 20 can be decreased, for example, to 1/5 or less as compared with the operational amplifier having NPN transistors in its input stage, since it is not necessary that the voltage drop in the detecting resistor 60 is increased. Therefore, the power consumption of the detecting resistor 60 and the heat loss thereof can be reduced. Thus, not only will the power loss of the detecting resistor 60 be decreased but also less consideration has to be given to its heat resisting property.

The comparison amplifier 401 at its negative

input terminal is connected through the resistor 412 to the point between the transistor 405 and the resistor 60. Therefore, the negative input terminal of the amplifier 401 is supplied with the detected voltage  $V_s$  corresponding to the current  $I$  flowing through the electromagnetic winding 20. A feedback circuit including the parallel connection of the capacitor 410 and the zener diode 411 is inserted between the negative input terminal and the output terminal of the comparison amplifier 401. The capacitor 410 is for the phase compensation of the amplifier 401. The zener diode 411 functions as the voltage limiter of the amplifier 401. The zener diode 411 suppresses over-bias to the forward-stage driving transistor 403 at the starting operation, and reduces overshooting of the current  $I$ . The positive input terminal of the amplifier 401 is connected to the reference voltage supply means 50, and receives the first reference voltage  $V_{R1}$  or the second reference voltage  $V_{R2}$  from the supply means 50. The output of the amplifier 401 is applied to the base of the transistor 403 to cause the difference between the first reference voltage  $V_{R1}$  or the second reference voltage  $V_{R2}$  and the detected voltage  $V_s$  to become zero.

The positive input terminal of the comparison amplifier 401 is connected to a resistor 501 of the reference voltage supply means 50 by means of a slider, and is also connected to another resistor 502. The first reference voltage  $V_{R1}$  is supplied by the resistor 501. The second reference voltage  $V_{R2}$  is obtained by inserting the resistor 502 in parallel with the part of the resistor 501 below the slider. The resistor 501 is connected in parallel to a zener diode 503. The anode of the zener diode 503 is grounded, and the cathode thereof is connected through a constant-current FET 504 to the power source line. The other resistor 502 with its one end connected to the positive input terminal of the amplifier 401 has the other end grounded through a collector-emitter circuit of a switching transistor 505. By means of such connections between the resistors 501, 502 and the zener diode 503, a constant voltage is applied to the resistors 501, 502. Therefore, the first reference voltage  $V_{R1}$  and the second reference voltage  $V_{R2}$  do not fluctuate even when the source voltage fluctuates.

The switching transistor 505, with a resistor 506, a comparator 507, resistors 508, 509 and a capacitor 510, constitute a switching means. This switching means inserts the resistor 502 in parallel with the resistor 501, or breaks the parallel connection of resistor 502 and resistor 501. The resistors 508, 509 and the capacitor 510 constitute a time-constant circuit. The base of the transistor 505 is connected through the resistor 506 to the output terminal of the comparator 507. The positive input terminal of the comparator 507 is con-

nected through the resistor 508 to the base of the forward-stage driving transistor 403, and also grounded through the parallel connection of the resistor 509 and the capacitor 510. Consequently, the positive input terminal of the comparator 507 is supplied with an input voltage  $V_c$  rising in accordance with the time constant determined by the resistors 508, 509 and the capacitor 510, when the transistor 304 is cut off. The negative input terminal of the comparator 507 is connected to the positive input terminal of the comparison amplifier 401. Therefore, the negative input terminal of the comparator 507 is supplied with the first reference voltage  $V_{R1}$  or the second reference voltage  $V_{R2}$ . The comparator 507 makes the transistor 505 conduct when the input voltage  $V_c$  reaches the first reference voltage  $V_{R1}$ , and makes the transistor 505 cut off when the input voltage  $V_c$  becomes the second reference voltage  $V_{R2}$  or less. The resistor 502 is inserted in parallel with the resistor 501 when the transistor 505 is conductive. The parallel connection of the resistor 502 and the resistor 501 is broken when the transistor 505 is cut off.

Fig. 4 shows the operational time chart of the device of Fig. 3. The driving signal  $V_i$ , the current  $I$ , the detected voltage  $V_s$ , the input voltage  $V_c$ , the first reference voltage  $V_{R1}$  and the second reference voltage  $V_{R2}$  are shown in Fig. 4.

If the driving signal  $V_i$  is not applied to the input terminal IN, the photo-transistor 303 is in its "off" state, and the switching transistor 304 is conductive since the transistor 304 is supplied with base current through the resistor 305. Therefore, the base potential of the forward-stage driving transistor 403 is approximately 0 (V). No current flows through the electromagnetic winding 20 because the transistors 403 and 405 are not driven. On the other hand, since the input voltage  $V_c$  applied to the positive input terminal of the comparator 507 is approximately 0 (V), the switching transistor 505 is in its "off" state. Consequently, the positive input terminal of the amplifier 401 is supplied with the first reference voltage  $V_{R1}$  by means of the resistor 501. The negative input voltage of the amplifier 401 is zero because the current  $I$  is zero. Therefore, the output voltage of the amplifier 401 is saturated in the sense necessary to provide the current  $I$  for the electromagnetic winding 20. However, since this saturation voltage is limited by the zener diode 411, the amplifier 401 is prevented from oversupplying base current to the forward-stage driving transistor 403 when the transistor 304 is cut off, and overshooting of the current  $I$  is thereby suppressed.

If the driving signal  $V_i$  is supplied to the input terminal IN, the photo-transistor 303 is conductive. Therefore, the base potential of the switching transistor 304 becomes approxi-

mately zero, and the transistor 304 is cut off. Consequently, the base of the forward-stage driving transistor 403 is supplied with the output of the amplifier 401, and then, the final-stage driving transistor 405 is driven. Accordingly, the starting current  $I_s$  begins to flow through the electromagnetic winding 20. As shown in Fig. 4, the starting current  $I_s$  rises freely until the detected voltage  $V_s$  (the voltage drop of the detecting resistor 60) reaches the first reference voltage  $V_{R1}$ , and then the starting current  $I_s$  is controlled so that the detected voltage  $V_s$  corresponds to the first reference voltage  $V_{R1}$ . Consequently, the starting current  $I_a$  is controlled at a constant value as shown in Fig. 4. This constant value is set to a current value lower than the maximum value  $IA_{max}$  in Fig. 2.

When the switching transistor 304 is cut off, the input voltage  $V_c$  applied to the positive input terminal of the comparator 507 rises according to the time constant determined by the resistors 508, 509 and the capacitor 510. When the input voltage  $V_c$  attains the first reference voltage  $V_{R1}$ , the output of the comparator 507 inverts to its high level H. Thus, the switching transistor 505 is conductive, and the resistor 502 is inserted in parallel with the resistor 501. Consequently, the second reference voltage  $V_{R2}$  lower than the first reference voltage  $V_{R1}$  is supplied to the amplifier 401 and the comparator 507.

The amplifier 401, therefore, reduces the mean output voltage so that the detected voltage  $V_s$  corresponds to the second reference voltage  $V_{R2}$ . Thus, the current  $I$  is reduced to the holding current  $I_b$  lower than the starting current  $I_a$  as shown in Fig. 4.

The input voltage  $V_c$  of the comparator 507 decreases in accordance with the reduction of the mean output voltage of the amplifier 401. However, since the reference voltage applied to the negative input terminal of the comparator 507 changes into the second reference voltage  $V_{R2}$  lower than the first reference voltage  $V_{R1}$ , the output level of the comparator 507 is not inverted. Therefore, the transistor 505 continues in its "on" state.

If the driving signal  $V_i$  comes to an end, the switching transistor 304 is again conductive. Therefore, the driving transistor 403 and 405 are cut off, and the current  $I$  is zero. Since the input voltage  $V_c$  becomes less than the second reference voltage  $V_{R2}$  because of the "on" state of the transistor 304, the output of the comparator 507 inverts to its low level L. Thus, the switching transistor 505 is cut off, and the first reference voltage  $V_{R1}$  is supplied again to the amplifier 401 and the comparator 507.

Fig. 5 shows starting characteristic curves given by the constant current control of the starting current (i) according to the present invention as shown in Fig. 4 and (ii) according to the uncontrolled starting current as shown

in Fig. 2. In Fig. 5, the curve (A) shows the variation of the starting current given by the constant current control, and the curve (A') in broken line shows that given in the absence of such control. The curve (B) shows the variation of the magnetic flux of the electromagnetic winding given by the constant current control, and the curve (B') shows that given by the absence of such control. The curve (C) shows the variation of the generated force given by the constant current control, and the curve (C') shows that given in the absence of such control. The curve (D) shows the movement of the valve given by the constant current control, and the curve (D') shows that given in the absence of such control. As apparent from Fig. 5, even when the starting current is made constant after an initial rise, there is scarcely any difference with respect to the generated force and the valve movement, between the constant current and the absence of control.

As described in detail, the current controlling device according to the present invention can reduce the heat loss in the electromagnetic winding, since the starting current is regulated to a constant value lower than the maximum value  $IA_{max}$  obtained if the starting current is allowed to rise freely. Further, the present current-controlling device can control an electromagnetic appliance stably even if the source voltage fluctuates, since the first and second reference voltages are controlled at constant voltages, respectively.

It should be understood that the embodiment of the invention disclosed above is merely illustrative.

#### CLAIMS

1. A current-controlling device for an electromagnetic winding comprising:

as input circuit for receiving a driving signal; reference voltage supply means responsive to the driving signal to supply a first reference voltage or a second reference voltage lower than the first reference voltage, the first and second reference voltages being controlled at substantially constant respective values, the first reference voltage being supplied up to a predetermined time after the input of the driving signal and the second reference voltage being supplied from the predetermined time after the input of the driving signal until the end of the driving signal;

a detector resistor connected to provide a signal representing current flowing through the electromagnetic winding; and current-control means receiving the first and second reference signals and the current-representing signal for supplying the electromagnetic winding with a starting current and a holding current, the starting current after initially increasing following the receipt of a driving signal being regulated to a substantially constant value under the control of the said current-representing

signal and the first reference voltage, and the holding current being regulated to another substantially constant value lower than the first constant value under the control of the

5 current-representing signal and the second reference voltage.

2. A current-controlling device according to claim 1, wherein the reference voltage supply means includes a first resistor for providing

10 the first reference voltage, a further resistor to be inserted in parallel with the first resistor for providing the second reference voltage, switching means for inserting the further resistor in parallel with the first resistor after the

15 predetermined time from the input of the driving signal, and for breaking the parallel connections of the further resistor and the first resistor at the end of the driving signal, and wherein the current-control means comprises a

20 comparison amplifier circuit for providing an output signal to make the detected voltage coincide with the first reference voltage or the second reference voltage, and a driving circuit for controlling the current flowing through the

25 electromagnetic winding on the basis of the output of the comparison amplifier circuit.

3. A current-controlling device according to claim 2, wherein the reference voltage supply means includes a zener diode inserted in parallel with the first resistor.

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4. A current-controlling device according to claim 2, wherein the switching means comprises a time-constant circuit for receiving the output of the comparison amplifier circuit, a

35 comparator for receiving the output of the time-constant circuit and the reference voltage applied to the comparison amplifier circuit, and a switching transistor for controlling the parallel insertion of the further resistor on the basis

40 of the output of the comparator.

5. A current-controlling device according to claim 2, wherein the comparison amplifier circuit has a feedback circuit including a zener diode.

6. A current-controlling device according to claim 1, wherein the input circuit receives the driving signal through a photo-coupler.

7. A current-controlling device for an electromagnetic winding comprising:

50 an input circuit for receiving a driving signal; reference voltage supply means for supplying a first reference voltage or a second reference voltage lower than the first reference voltage, the first and second reference voltages being controlled at constant voltages,

55 respectively, and the second reference voltage being supplied until the end of the driving signal after a predetermined time from the input of the driving signal, instead of the first reference voltage;

60

a detecting resistor for detecting current flowing through the electromagnetic winding; and

current control means for supplying the

65 electromagnetic winding with a starting current

and a holding current, the starting current being regulated to a constant value after an initial rise on the basis of the voltage supplied by the detecting resistor and the first reference voltage, and the holding current being regulated to another constant value lower than the said constant value on the basis of the voltage supplied by the detecting resistor and the second reference voltage.

75 8. A current-controlling device substantially as herein described with reference to the accompanying drawings.

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